UKERC

UKERC RESEARCH ATLAS: FUEL CELLS

Prepared by Prof Nigel Brandon, Imperial College London
Last Updated: 27 December 2013

1. Overview

Return to Top

Characterisation of the field

Fuel Cells are an energy conversion technology capable of converting a wide range of fuel types to electricity, and in some cases heat, at high efficiency and with low emissions, compared to other technologies. Fuel cells are now entering commercial markets in Europe, Asia and North America, across a range of applications. Fuel cells are electrochemical devices, comprising an ionically conducting electrolyte and two electrochemically active electrodes, an anode where fuel is oxidised, and a cathode where an oxidant (usually air) is reduced. These electrodes are contacted by electronically conducting current collectors to collect/inject electrons into the electrochemically active regions. Practical devices commonly contain many fuel cells connected by interconnects/bipolar plates in electrical series and parallel in a fuel cell stack to produce useful power outputs. Stacks are integrated into fuel cell systems, the design of which is specific to the application of interest. For example fuel cells generally require hydrogen rich gases, and many fuel cell systems therefore contain reformers to enable direct operation on fuels such as natural gas or LPG, along with clean up systems where these are needed, for example for fuels high in sulphur. The fuel of choice depends on the application and the type of fuel cell used. Fuels include hydrogen, methanol, ethanol, natural gas, LPG, bio-gas, diesel and gasoline. There are also a range of biological fuel cells being developed. Fuels cells are being developed for a wide range of applications, ranging from a few Watts for battery replacement for consumer goods such as laptops and mobile phones, 100's Watts for small generator replacement, kW's for micro Combined Heat and Power or auxiliary power units, 10 kW's for hydrogen fuelled fuel cell engines, to 100 kW's or MW's for power generation on natural gas/bio-gas. There are a number of different fuel cell types being developed by companies and universities in the UK including; alkaline conducting, proton conducting polymer, and solid oxide, and this is reflected in the UK research base. Fuel cell research and development is very much a multi-disciplinary field, encompassing issues such as material science and engineering, catalysis, electrochemistry, thermal fluids, system design, integration and control, and power electronics.

Research challenges

The key research challenges relate to continued cost reduction at the product level whilst demonstrating reliability and durability in fuel cell systems in real world applications. Cost reduction is being addressed in different ways, depending on the application, for example by the integration of new materials, by careful materials and stack engineering, and/or via innovative system design, by component development, and by a combination of these at the sub-system and system level. Many of these challenges are the domain of industrial R&D. Extensive laboratory and field trials of cells, stacks and systems by industry is improving the understanding of failure modes in fuel cell devices. This is being supported by academic research to help understand the causes of degradation, working with industry to develop mitigation strategies. There is also interest in extending the temperature ranges of operation of both polymer fuel cells and solid oxide fuel cells, to open up new system design opportunities. To help understand and mitigate failure modes, there are research challenges involved in developing new tools and methods that allow the *in-situ* characterisation of working fuel cell devices, and the detailed characterisation of material microstructure and interfaces, especially after extended operation. There remain significant research opportunities to; develop new materials to simplify engineering challenges, increase functionality, or replace expensive components; better understand the fundamental long term behaviour of many of the materials used in fuel cell systems, and; develop improved and validated cell, stack and system design tools.

2. Capabilities assessment

Return to Top

The UK has a long and impressive track record in fuel cell research and development. The UK has developed a number of leading, and highly innovative, industry programmes, supported by a strong academic base in both science and engineering.

Table 2.1 UK Capabilities

UK capability	Area	Market Potential
High	▪ FC materials science and engineering ▪ Cell and stack engineering ▪ Fuel processing ▪ System engineering ▪ Selected balance of plant components ▪ Fuel cell manufacture ▪ Techno-economic modelling	Global market Global market Global market Global market Global market Global market Global market
Medium	▪ System demonstration ▪ Control systems ▪ Power electronics	UK application but a global market Global market UK application but a global market
Low	▪ Product trials	UK application but a global market

3. Basic and applied strategic research

Return to Top

21 Universities and 1 Government research laboratory have significant fuel cell research activities. The full list is given in Table 3.1, with the following text providing an overview. Imperial College London has over 60 staff and researchers active in fuel cell research across a wide range of activities, from fundamental science, through engineering, to policy. Ceres Power was spun out of one area of research at Imperial College in 2001, while Imperial College and UCL are jointly developing a novel low cost fuel cell technology through the Carbon Trust Polymer Fuel Cell Challenge, established to help pull through innovative fuel cell technologies. The EPSRC funded 'Supergen' programme in fuel cells is jointly led out of Imperial College and Newcastle University, and also involves St Andrews University, Cambridge University, Strathclyde University, and University College London, though this will end in early 2014. The EPSRC bio-fuel cell Supergen programme led by Oxford also comes to an end in 2014. This consortium is led out of Oxford University, and also involves the Universities of Glamorgan, Surrey, Univ. West of England, Newcastle, Glasgow, UCL, and East Anglia. The new EPSRC funded Supergen Hub for Hydrogen and Fuel Cells (H2FC SUPERGEN) started in 2012, and is a collaboration between seven Universities: Imperial, Bath, St Andrews, Newcastle, UCL, Ulster, and Birmingham, supported by a large number of stakeholders in industry, government and the funding agencies, with over 330 members to date. Newcastle University have a significant fuel cell programme, well known for their work on Direct Methanol and high temperature PEM fuel cells, but with an active programme in bio fuel cells and SOFCs. St Andrews are internationally regarded for their strong track record in materials chemistry, with a particular focus on SOFC materials. Loughborough University have programme in PEMFC science and engineering with a particular focus on automotive fuel cell R&D, together with some work on SOFCs. The Universities of Birmingham, Nottingham and Loughborough jointly run the EPSRC funded Doctoral Training Centre in hydrogen, fuel cells and their applications, led out of Birmingham University. Other academic centres with fuel cell programmes include the Universities of Cranfield, Keele, Kings College, Queens Belfast, Reading, Southampton, Oxford and Warwick. The National Physical Laboratory have an active fuel cell programme, looking at the development and application of measurement technologies to the fuel cell sector. EPSRC currently support some 26 research grants in fuel cells at UK universities worth a total of over £31M (within this there are 4 large grants with a combined value of £16.6M, namely the CDT in hydrogen and fuel cells, fuel cell Supergen, hydrogen and fuel cell Supergen, and bio-fuel cell Supergen), noting that funding awarded by the Research Councils for fuel cells on an annual basis has been in quite steep decline in recent years, from over £9M awarded in 2009 down to under £3M awarded in 2012. . Outside of these four large grants, the balance of £14.5M is split across low temperature fuel cells (£5.0M), Solid oxide fuel cells (£7.8M) and bio fuel cells (£1.5M). No new TSB calls were announced in 2013 for fuel cells, £7.5M having been awarded in 2012 for Hydrogen and Fuel Cells: Whole System Integration and Demonstration, with another £5M for Fuel Cells Manufacturing and the Supply Chain to be awarded in 2014. Some of the DECC Energy Entrepreneurs Fund was awarded to support fuel cell companies.

Table 3.1: Research Funding

Programme	Funding Agency	Description	Committed Funds	Period	Representative Annual Spend
SUPERGEN - Fuel Cells	EPSRC	A fuel cell research consortium looking at SOFC and PEMFC, comprising Imperial College, Newcastle Univ., St Andrews Univ., Cambridge Univ., University College London, Herriot Watt University, Johnson-Matthey Fuel Cells, Ceres Power, and Intelligent Energy.	£3.6m	9/09 – 2/14	£0.8m
SUPERGEN - Biological Fuel Cells	EPSRC	A biological fuel cell research consortium comprising the Universities of Surrey, Oxford, Glamorgan, UCL, Glasgow, East Anglia and Univ West of England.	£3.3m	4/10 – 4/14	£0.8m
CDT Hydrogen Fuel cells and their applications	EPSRC	Doctoral Training Centre in Hydrogen, Fuel Cells and their Applications, led by Univ's Birmingham, Nottingham and Loughborough.	£5.5m	10/09-03/18	£0.5m
Responsive Mode	EPSRC	22 current awards	£14.5m	Around 3 years	£4.8m
SUPERGEN – Hydrogen and Fuel Cells Hub (H2FC Supergen)	EPSRC	A research consortium looking at hydrogen and at fuel cells. Research is focussed onto science, engineering and technology development, as well as addressing wider issues about the role and benefits that these technologies bring to future low carbon energy systems. Academic partners are Imperial College London, Bath, St Andrews, Newcastle, UCL, Ulster and Birmingham. The programme is in partnership with a large number of stakeholders in industry, the funding agencies and government.	£4.1m	5/12-4/17	£0.8m

Table 3.2: Key Research Providers

Name	Description	Sub-topics covered	No of staff	Field
Energy Futures Lab, Imperial College London	With a more than 30 year track record in fuel cell R&D, Imperial College has a multi-disciplinary team focussed on fuel cell development, with active programmes in Chemistry, Chemical Engineering, Materials, Mechanical Engineering, Electrical Engineering, Earth Science and Engineering and Environmental Policy. This operates as part of the Energy Futures Lab, a Lab dedicated to tackling the scientific challenges posed by the worlds demand for energy.	• SOFC materials • PEMFC membranes and catalysts • Cell fabrication and testing • In-situ cell and stack diagnostics • Stack and system dynamics • Materials characterisation • Stack testing to 4 kWe • Balance of plant • Cell, stack and system modelling • System control and power electronics • Electrical networks • Fuel infrastructure • Energy policy • Fuel cell economics and environmental impact	60	
Fuel Cells and Hydrogen Research Group, Newcastle University	The Hydrogen and Fuel Cell research has evolved from the traditional strengths at Newcastle in electrochemical science and engineering, membrane processes and reactors as well as interdisciplinary research in electrochemistry, electrochemical engineering, membranes, materials and surface science.	• Intermediate Temperature water electrolysers • Alkaline membrane materials for electrolysers and fuel cells • Intermediate temperature polymer electrolytes for electrolysers and fuel cells • Oxygen reduction electrocatalysts for polymer electrolyte fuel cells • Oxygen evolution electrocatalysts for water electrolysers • Hydrogen evolution electrocatalysts • Modelling low and intermediate temperature fuel cells • Solid acid electrolytes • CO and methanol tolerant electrodes for advanced PEM FCs • Modelling of direct methanol anodes and	30	

Name	Description	Sub-topics covered	No of staff	Field
		FCs • Alkaline fuel cells • Mixed reactant fuel cells • Microbial fuel cells • Biological fuel cells • Oxidation catalysis and electrocatalysis in SOFCs • Integration of hydrogen storage systems with SOFC systems • Alternative SOFC electrolyte materials and fabrication processes		
The School of Chemistry, University of St Andrews	The School of Chemistry has a particularly successful and broadly based materials research activity. The focus of this activity is clustered around the St Andrews Centre for Advanced Materials, which has strong links with the School of Physics. This grouping brings together those working in Energy Materials, Porous Solids, Catalysis and Surface Science as well as physicists and geoscientists. There is a significant level of applied research interfacing with new battery technologies and Materials for Clean Energy.	• Electrically-conducting and catalytically active materials for SOFCs • Proton-conducting ceramics in novel electrochemical reactors for combined chemicals synthesis and electrical power generation • Alternative oxygen-ion conductors • Proton conducting electrolytes in the temperature range 500-750°C • High temperature fuel cells for transport applications • Alternative fuels such as biogas for power generation • Electrocatalysis at solid-electrolytes e.g. for the partial oxidation of hydrocarbons	30	
Nottingham Fuel	The Nottingham Fuel & Energy Centre	• Nanoporous ion conducting membranes for		

Name	Description	Sub-topics covered	No of staff	Field
and Energy Centre, School of Chemical, Environmental and Mining Engineering (SChEME), Nottingham University	conducts wide ranging research into fuels. This currently includes fuel cells and hydrogen storage.	fuel cells and batteries • Low energy and low emission electro-extraction of metals and alloys directly from solid oxides in molten salts to improve the energy efficiency of the process • Application of novel materials in electrochemical devices, including fuel cells, supercapacitors, rechargeable batteries, sensors, switchable membranes and etc		
Faculty of Engineering and Faculty of Science, Loughborough University	Fuel cell research at Loughborough University is spread over various Faculties, departments and research groups. These include the Combustion and Energy Conversion Research Group in the Department of Aeronautical and Automotive Engineering and the Department of Electronic and Electrical Engineering, both in the Faculty of Engineering, and the Electrochemistry research group in the Department of Chemistry Department of Chemistry, Faculty of Science.	• Fuel cells for automotive applications • Modelling of a fuel cell powered passenger car with a methanol reformer • Novel electrode fabrication technique development for use in Solid Polymer FCs • Modification of electrodes with conducting polymers for the development of new electrocatalytic systems for fuel cells • PEM fuel cell model development as a technology demonstrator and design tool • Modelling the dynamic and transient operation of the electrolyser and fuel cell in a stand-alone renewable energy system • Work within CREST on fuel cell research.		
Doctoral Training Centre in Hydrogen, Fuel Cells and their Applications, The Universities of Birmingham, Loughborough & Nottingham	Led by Birmingham University, this partnership runs the Doctoral Training Centre in Hydrogen, Fuel Cells and their Applications. This provides PhD training for 50 PhD students over 5 years, and it commenced in October 2009.	• Solid Oxide Fuel Cell Systems • Solid Oxide Fuel Cell Stack Engineering for Domestic Applications • Hydrogen Polymer Fuel Cell • Hybrid Vehicular Systems • MEA Engineering for Polymer Fuel Cell & DMFC Applications • Direct Methanol Fuel Cell Stack Engineering for Portable Applications		

Name	Description	Sub-topics covered	No of staff	Field
		• Alkaline Polymer Electrolyte Fuel Cells • Discovery of New Nano-Materials for Hydrogen Production & Storage • Discovery of non-PGM alloys Materials, Hydrogen Production from Biomolecules by Novel Methods • Development of Novel Pd Alloy Thin-films for Use in High temperature Hydrogen Membrane Reactors.		
University of Birmingham	Fuel cell research at Birmingham University is carried out in a number of Departments, including the Department of Chemical Engineering and the Department of Metallurgy and Materials.	• SOFC testing. • SOFC fuels and fuel processing • Materials specifications for electrolyte, electrodes and interconnects • Direct injection of various fuels, including methane, propane, butane, iso-octane, methanol, ethanol, ethers, biodiesel and biogas, into SOFCs • Operation of fuel cells on hydrogen from waste sugars • Flow and catalyst issues in SOFCs • Hydrogen storage and purification materials	30	
Defence College of Management and Technology and School of Engineering, Cranfield University	Fuel cell research at Cranfield University is mainly carried out at the Cranfield Forensic Institute within Cranfield University at the Defence College of Management and Technology. This is being funded to develop new and cost effective polymer electrolytes and ways of using these new materials more efficiently in fuel cells.	• Modelling and optimisation of fuel cell systems • Solid polymer fuel cells • Solid polymer electrolytes • Semi-permeable membranes and ion-exchange polymers		

Name	Description	Sub-topics covered	No of staff	Field
The Centre for Materials Research (CMR), Queen Mary, University of London	Fuel cell research at Queen Mary can be found in the School of Biological & Chemical Sciences and in the Materials Department. However, most research is done under the Centre for Materials Research.	• Experimental and modelling studies to design electrodes and interfaces • Biological fuel cells (BFCs) • Solid electrolytes or fast ionic conductors • Paint technology for the manufacture of fuel cell structures		
Department of Chemistry University of Reading	Fuel cell research at the University of Reading is based in the Department of Chemistry, within the Materials and Synthesis Group. Much of this work is carried out in close collaboration with Johnson Matthey plc.	• Polymeric materials for membrane-electrode assemblies of PEM fuel cells • Ionomer design, synthesis, and membrane fabrication • Membrane materials for hydrogen and DMFC fuel cells, and for hydrogen production by membrane electrolysis • High-proton-conductivity dopants for ionomer membranes		
Faculty of Engineering, Science and Mathematics Southampton University	Fuel cell research at Southampton University is carried out in the Electrochemistry & Surface Science group at the School of Chemistry and at the School of Engineering and the Environment.	• Development of improved biofuel cells (using three-dimensional electrodes and activated carbon surfaces) • In-situ diagnostics for PEM fuel cells • High throughput thin film materials synthesis and screening • PEM fuel cell • Hydrogen storage materials		
Department of Chemistry in the Faculty of	Fuel cell research can be found in the Department of Chemistry in the Faculty of Engineering and Physical Sciences	• Synthesis and characterisation of new materials for SOFCs • Computer modelling studies of SOFC		

Name	Description	Sub-topics covered	No of staff	Field
Engineering and Physical Sciences, Surrey University	and also at the UniS Materials Institute (UMI).	materials • Development of alkaline PEM fuel cells • Ionic and mixed conductors for fuel cells		
Faculty of Science, The University of Warwick	School of Engineering	• Development of new materials for fuel cell applications, including electrolyte materials • Novel compositions for electrode components • Coating technology for component manufacture • Development of modular, small-scale gas processing systems for hydrogen • Biomass conversion, integration with fuel cells		
Faculty of Natural Sciences, Keele University	Chemistry Department at the School of Physical and Geographical Sciences	• Fuel processing and internal reforming in SOFCs • Development of new anodes for internally reforming SOFCs • Carbon deposition on active components in fuel cells • Sulphur tolerance of active materials in SOFCs • SOFCs running on natural gas, propane/butane and higher hydrocarbons • SOFCs running on biogas and biomass • Partial oxidation and direct hydrocarbon oxidation in SOFCs		
University College London	Fuel cells are a growing area of research at UCL, with active programmes of work in the Departments of Chemistry, Chemical, Civil and Mechanical Engineering.	• PEMFC and SOFC development. • Nanomaterial synthesis for advanced SOFC electrodes. • High-throughput synthesis and screening of SOFC electrode materials. • Electrochemical techniques, *in situ*	25 staff and students	

Name	Description	Sub-topics covered	No of staff	Field
	The Electrochemical Innovation Lab in The Centre for CO_2 Technology has a major focus on fuel cell research and new state-of-the-art laboratory facilities are being built in the Dept. Mechanical Engineering for the development of hybrid fuel cell vehicles. Researchers at UCL are also active in the complimentary electrochemical technologies of advanced batteries, electrolysers, and supercapacitors.	diagnostics, sensors and instrumentation. • Techno-economic analysis. • Fuel cell systems design and optimisation • Fuel cell micro-grid design and optimisation. • Hydrogen storage and hybrid H_2/PEMFCs. • Bipolar plate design and the study of corrosion and its prevention. • Transport and marine applications for fuel cells. • Biofuel cells. • Fuel cells for micro-CHP. • Mechanical characterisation and accelerated testing of SOFC components. • Ceramic processing routes for SOFCs. • Molecular dynamics simulation of fuel cell electrodes. • Fuel cell hybrid vehicle technology development.		
Strathclyde University	Dept. Chemical & Process Engineering	• Ammonia and urea fuel cells. • Electrolyte and catalysts for high temperature PEMFCs. • Catalyst development for fuel cells. • SOFC materials. • Materials for alkaline membrane fuel cells.		
Oxford University	Dept. Chemistry	• Enzymatic fuel cells. • Catalysis.		
Cambridge University	Dept. Engineering. Turbomachinery, energy and fluid mechanics Division	• Proton transport in PEMFC membranes. • SOFC-GT systems. • Low cost PEMFC catalysts. • PEMFC electrolytes.		

Name	Description	Sub-topics covered	No of staff	Field
		• SOFC materials.		
Sustainable Environment Research Centre (SERC) and Advanced Control and Network Technology Centre (AC&NT), University of Glamorgan	SERC's multi-disciplinary team has a broad portfolio of hydrogen, anaerobic system and fuel cell R&D, spanning fundamental materials research through to industrial research and testing. Biological and materials research is concentrated at the Glyntaff campus, with renewable systems R&D carried out at the Hydrogen Research Centre at Baglan. The University's Advanced Control and Network Technology Research Unit has a focus on fuel cell control and electrical systems development, particularly for automotive applications.	• Microbial Fuel Cells and bio-electrocatalytic systems • Novel nanomaterials for PEM FC membranes • FC system modelling for stationary and automotive applications • Sustainable fuel infrastructure modelling and planning • Novel biogas clean up mechanisms for SOFC integration • SOFC cell testing (tolerance to biogas impurities) • Life Cycle Analysis of hydrogen/ FC systems and Biogas/FC systems • Advanced control for automotive and stationary fuel cell systems • Fuel cell integration with hybrid vehicle drive trains • Safety of Fuel Cell and Hydrogen Systems	50 (SERC) + 14 (AC&NT)	

4. Applied research and development

Return to Top

Applied research in the fuel cell sector is largely undertaken by the fuel cell developers, with the support of the supply chain, and some academic institutions. Funding for fuel cell related applied research is provided by the Technology Strategy Board (TSB) collaborative research and development programme, the Carbon Trust R&D programme, and the DECC Energy Entrepreneurs Fund. The Energy Generation and Supply KTN supports a network in fuel cells and hydrogen. This covers large stationary fuel cells, used primarily for distributed power generation and frequently deployed in combined heat and power (CHP) mode; small stationary fuel cells, used in residential applications, providing hot water and electricity to householders; transport fuel cells, for use on land, sea and air; Portable fuel cells, primarily for deployment in consumer electronics, but also for military use.

Good sources of information on commercial developments can be found on the web sites of Fuel Cell today and UK Hydrogen and Fuel Cell Association. The following analysis focuses on developers of fuel cells and fuel cell stacks, though it is recognised that applied research and development of other balance of plant components is also necessary to produce commercial fuel cell products. These include reformers, compact heat exchangers, compressors, valves, and power electronics, for example.

Table 4.1: Research Funding

Programme	Funding Agency	Description	Committed Funds	Period	Representative Annual Spend
TSB	BIS	The Technology Strategy Board invested £7.5m in 2012 in collaborative research and development projects involving fuel cells and hydrogen energy systems, with a focus on their evaluation and demonstration in integrated energy systems.	£7.5m.	Around 3 years	£2.5m

Table 4.2: Key Industrial Research Providers

Name	Description	Sub-topics covered	No of staff	Sector
Acal Energy	ACAL Energy is developing fuel cell systems, modules and consumable chemicals for a range of uses including stationary, residential and automotive applications requiring larger than 1 kW of power, based around platinum free regenerating redox catalysts for the oxygen side of PEMFC type fuel cells.	Redox catalysts Liquid cathode fuel cells		
AFC Energy	AFC Energy is developing alkaline fuel cell technology, with a focus on fuel cell applications in industrial processes where hydrogen is available.	Alkaline fuel cells, stacks and systems.		
Bac2	Bac2 develops commercial-scale electrically conductive polymer composites for application as low temperature fuel cell bipolar plates and end plates.	Carbon composite bipolar plates	8	
Ceramic Fuel Cells	The European arm of Australian based Ceramic Fuel Cells Ltd. CFCL is developing SOFC products for small-scale on-site micro combined heat and power (m-CHP) and distributed generation units that co-generate electricity and heat for domestic use.	Solid Oxide Fuel Cells		
Ceres Power	Ceres Power is an AIM-quoted alternative energy company based in the UK, developing metal supported solid oxide fuel cell technology for use in small scale combined heat and power products for the residential sector and in energy security applications.	Metal supported solid oxide fuel cells, stacks and systems	Around 70	
Diverse Energy	Diverse Energy is developing 2-20kW fuel cell systems range for remote power requirements throughout the world, with a focus on powering remote telecom sites in regions without a reliable electrical grid. The company is focussed on three fuels, anhydrous ammonia, propane, and pure hydrogen.	PEM fuel cell systems.		
Intelligent Energy Ltd	Intelligent Energy develops products based around PEMFCs, supplying fuel cell, fuel processing, hydrogen generation and desulphurisation technologies for application in four target markets: aerospace and defence; distributed generation and portable power; oil and gas and motive power. They have a joint venture with Suzuki to establish the SMILE FC System Corporation.	PEM fuel cell stacks and systems	Around 250	
Johnson Matthey Fuel	Johnson Matthey Fuel Cells is a global business dedicated to the supply of high quality fuel cell components and backed by full research and	PEM fuel cells Direct methanol fuel	Around 160.	

Name	Description	Sub-topics covered	No of staff	Sector
Cells	development efforts. The business has sites in the UK, USA, Japan, Hong Kong, Korea and Taiwan. Johnson Matthey Fuel Cells develops and manufactures precious metal catalyst systems and membrane electrode assemblies for a range of fuel cell applications.	cells Phosphoric acid fuel cells		
Logan Energy	Logan Energy has expertise in the application of fuel cells to electricity generation, combined heat and power (CHP), heat cooling and power (CCHP or tri-generation) utilising a number of base fuels ranging from natural gas and LPG to bio-fuels. The company has installed over 125 fuel cells across the US as well as Iceland, Puerto Rico and the UK, with capacities scaled from 5 to 600 kilowatts.	Fuel cell applications engineering		
QinetiQ	QinetiQ has programmes on PEMFCs, direct ethanol fuel cells, high sulphur fuel reformers, and solid state hydrogen generators.	PEM fuel cells Direct ethanol fuel cells		
Rolls-Royce Fuel Cells Systems Ltd (part of LG Fuel Cell Systems)	51% of Rolls-Royce Fuel Cell Systems Limited (RRFCS) was bought by LG of Korea in 2012 to create LG Fuel Cell Systems. The company is developing a single cycle high efficiency solid oxide fuel cell system for distributed power generation. Full system cycle pressurized tests at the Derby R&T facilities have been conducted at multi-kW scale. LGFCS is a partner in the US SECA programme.	Solid oxide fuel cell gas turbine hybrids		

5. Development and Demonstration Funding

Return to Top

There has been limited funding for fuel cell demonstration activities in the UK.

Table 5.1 Demonstration Funding Programmes

Programme	Funding Agency	Description	Number of projects	Committed funds	Period	Representative Annual Spend
London Hydrogen bus programme	Transport for London (TfL) and EU.	Three hydrogen fuelled PEMFC powered buses are operating on commercial routes in London.				
Aberdeen hydrogen bus programme	Scottish Government, Scottish Enterprise, Aberdeen council, EU.	Ten hydrogen fuel cell buses to be operating in Aberdeen by 2014.				

Table 5.2: Major Demonstration Projects

Name	Description	Sub-topics covered	Funding	Period
Ene.field fuel cell mCHP demonstration	Started in 2012, nine European micro FC-CHP manufacturers (including the UK's Ceres Power) will deliver trials across 12 EU Member States. The project will deploy approximately 1,000 residential installations, establish the macro-economics and CO2 savings of the technologies in the European markets, and assess the socio-economic barriers to widespread deployment of micro FC-CHP. Article summarising the project	• Field trials	Costs of €53 million (appr. $71.46 million dollars) with €26 million in European funding from the EU's Seventh Framework Programme. The ene.field project is cofunded by the partners and the European Commission's Fuel Cells and Hydrogen Joint Undertaking Programme (FCH JU).	2012-2017

6. Research Facilities

Return to Top

There are no national UK fuel cell research facilities.

7. Networks

Return to Top

The UK Hydrogen and Fuel Cell Association (UK HFCA) acts on behalf of UK fuel cell stakeholders to accelerate the development and commercialisation of fuel cells in the UK. It provides a point of contact and an up-to-date view on research, development and demonstration priorities for Government, other funding agencies and opinion formers. The Fuel cell and hydrogen group of the energy generation and supply KTN has been formed to embed fuel cell technology into the wider energy landscape, replacing the previous low carbon and fuel cell KTN.

Table 7.1 Networks

Network	Established	Description	Membership	Activities
H2FC SUPERGEN	1st May 2012	Funded by EPSRC, the Hydrogen and Fuel cell SUPERGEN Hub integrates across the entire Hydrogen and Fuel Cell landscape. Although the initiative is UK-based the Hub has strong international links. H2FC SUPERGEN utilises networks, knowledge exchange and stakeholder (including outreach) engagement, community building, and education to develop a coherent research community in the hydrogen and fuel cell sectors.	330 members	
UK Hydrogen and Fuel Cell Association		The UK Hydrogen and Fuel Cells Association (UK HFCA) launched as the result of the merger of Fuel Cells UK and the UK Hydrogen Association. The industry body provides a common voice for the sector in the UK.	27 members from industry and academia	• Membership comprises the leading fuel cell and hydrogen companies in the UK as well as a range of stakeholders, from energy utilities to component developers, fuel suppliers and others involved n the industry.
Fuel cell and hydrogen group of the Energy Generation & Supply		A BIS supported knowledge transfer network. Previously part		• Organises meetings and discussion groups, including

KTN		the Low Carbon and Fuel Cell KTN.		on-line events. • The fuel cell and hydrogen group of the EG&S KTN covers: • Large stationary fuel cells, used primarily for distributed power generation and frequently deployed in combined heat and power (CHP) mode • Small stationary fuel cells, used in residential applications, providing hot water and electricity to householders • Transport fuel cells, for use on land, sea and air • Portable fuel cells, primarily for deployment in consumer electronics, but also for military use • Hydrogen production, distribution, storage and use.
Scottish Hydrogen & Fuel Cells Association (SHFCA)		Industrialists and researchers in Scotland have come together to form the Scottish Hydrogen and Fuel Cell Association (SHFCA). The body has been set up to promote and develop Scottish expertise in fuel cells and hydrogen technologies.	52 members	• The Scottish Hydrogen and Fuel Cell Association represents, promotes and develops Scottish interests in fuel cells, both nationally and internationally, and coordinates and promotes members' views on current and future research and development
Hydrogen London		The principal objective is to work towards the establishment of a hydrogen economy for London and the UK. It aims to:	31 members	

		• Establish and maintain dialogue among all sectors/actors relevant to the hydrogen economy. • Prepare and disseminate relevant materials. • Develop the Hydrogen London Action Plan as a route map for clean energy. • Provide a platform for funding bids and initiation of projects.		
Cenex		Cenex is a delivery agency established with support from the Department for Business, Innovation and Skills to promote UK market development and competitiveness in low carbon and fuel cell technologies for transport applications. Cenex's principal focus is on catalysing market transformation projects linking technology providers and end users. As part of this work, it runs a number of programmes for UK national and regional government, including the Low Carbon Vehicle Procurement Programme and the Low Carbon Knowledge Transfer Network.		• Three programmes are currently active: advantage niche vehicles, low carbon vehicle procurement programme, and the infrastructure grant programme. • Low carbon vehicle events and meetings. • Low carbon vehicle demonstration.

8. UK Participation in EU Framework Programmes

Return to Top

The EU has a long standing, broad, and relatively well funded programme in fuel cell research. Research has primarily focussed on polymer fuel cells (PEMFCs), molten carbonate fuel cells (MCFCs) and solid oxide fuel cells (SOFCs), for transport, portable and stationary applications. Much of the work to date has addressed basic research and development challenges, with significant levels of activity in the major European research laboratories such as Riso and Julich, partnered with industry and supported by academic institutions. The organisation Fuel Cell Europe aims to promote fuel cells as one of the key technology solution for the European sustainable energy system in transport, stationary power and portable application.

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is a public private partnership supporting research, technological development and demonstration (RTD) activities in fuel cell and hydrogen energy technologies in Europe. It was established in May 2008. The aim of the FCH JU is to accelerate the market introduction of fuel cell and hydrogen technologies, realising their potential as an instrument in achieving a carbon-lean energy system. Most of the EU funding in the fuel cell area is now co-ordinated through this body. The FCH JU awards proposal on an annual basis.

The British Standards Institution has a committee, GEL/105, "Fuel Cell Technologies", which mirrors the work of the International Electrotechnical Commission Technical Committee on Fuel Cells (IEC/TC 105), and adopts the European Standards as appropriate with minimum modifications as British Standards. A list of current fuel cell British standards is given at the end of this section.

British Fuel cell standards

Number	Title	ISBN	Publication Date
DD IEC/TS 62282-1:2010	Fuel cell technologies. Terminology	0 580 61737 9	31st May 2010
BS EN 62282-2:2004	Fuel cell technologies. Fuel cell modules	0 580 50869 1	10th Dec 2004
BS EN 62282-3-1:2007	Fuel cell technologies. Stationary fuel cell power systems. Safety	0 580 53370 9	31st Jul 2007
BS EN 62282-3-2:2006	Fuel cell technologies. Stationary fuel cell power systems. Performance test methods	0 580 49026 2	31st Jul 2006
BS EN 62282-3-3:2008	Fuel cell technologies. Stationary fuel cell power systems. Installation	0 580 53774 5	30th Sep 2008
BS EN 62282-5-1:2007	Fuel cell technologies. Portable fuel cell power systems. Safety	0 580 53773 8	31st Jul 2007
BS EN 62282-6-100:2010	Fuel cell technologies. Micro fuel cell power systems. Safety	0 580 54195 7	31st May 2010
BS EN 62282-6-200:2008	Fuel cell technologies. Micro fuel cell power systems. Performance test methods	0 580 54646 4	30th May 2008
BS EN 62282-6-300:2009	Fuel cell technologies. Micro fuel cell power systems. Fuel cartridge interchangeability	0 580 54647 1	30th Jun 2010

Table 8.1 EU Framework Programme

The following ongoing EU fuel cell programmes have UK partners.

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator	Total Funding	EU Funding	Duration	Annual Spend
PEMICAN https://www.pemican.eu/	PEMFC with low cost core shell catalysts for automotive applications	FCH JU	FCH JU 256798	Imperial College	CEA	€3.96m	€1.86m	36 months from Apr 1 2011	€1.3m
ENE.FIELD http://enefield.eu/about/	The Ene.field project will be a major step to overcoming the challenges of commercializing fuel cell technology used in Combined Heat and Power (mCHP) mode in residential buildings. The project allows a group of Europe's leading mCHP developers to embark on a large field validation of the technology under a common analysis framework. Ene.field will deploy and monitor around 1,000 new installations of residential fuel cell CHP across 12 key member states	FCH JU		British Gas, Ceres Power, Imperial College, Element energy	Cogen Europe	€5.29m	€2.593m	60 months from 1 Sep 2012	€1.0m
TOWERPOWER	Ammonia fuelled back up fuel cell power systems for telecoms applications.	FCH JU	FCH JU 279190	Diverse Energy, Balton CP, Renewtech	Diverse Energy	€9.4m	€4.9m	36 months from Nov 11	€3.1m
LASER-CELL http://www.laser-cell.eu/	Laser processed substrates for alkaline fuel cells	FCH JU	FCH JU 278674	AFC Energy	AFC Energy	€2.9m	€1.4m	36 months from Dec 11	€1m

METSAPP http://www.metsapp.eu/	Metal supported SOFCs	FCH JU	FCH JU 278257	St Andrews University	Topsoe fuel cells	€8m	€3.4m	36 months from Nov 11	€2.7m
SOFT-PACT	Large scale demonstration of SOFC generators	FCH JU	FCH JU 278804	EON UK, Ideal Boilers Ltd	EON UK	€10.3m	€4m	39 months from July 11	€3.4m
FCGEN	Develop and demonstrate a proof-of-concept complete fuel cell auxiliary unit on-board a truck	FCH-JU	FCH JU277844	Johnson Matthey	Volvo	€10.3m	€4.3m	36 months from Jan 11	€3.4m
High V. LO-City http://highvlocity.eu/	Deployment the latest generation of FCH buses in public transport operations	FCH JU	FCH-JU No 278192	Aberdeen city council	Van Hool	€31.6m	€13.5m	60 months from Jan 12	€6.2m
HyQ	Studies to support Regulation Codes and Standards organisations in order to normalize an acceptable fuel quality for PEMFCs	FCH JU	FCH JU 256773	Element energy, NPL, CCS Global	CEA	€3.7m	€1.4m	36 months from Mar 11	€2.2m
HYFACTS http://www.hyfacts.eu/	Develop and initiate dissemination of training material for Regulators and Public Safety Officials related to hydrogen technologies	FCH JU	FCH JU 256823	HSL, CCS Global, Ulster University	TUV-SUD	€4m	€2m	30 months from Feb 11	€1.5m
SUAV http://www.suav-project.eu/SUAV.html	Microtubular Solid Oxide Fuel Cell Power System development and integration into a Mini-UAV	FCH JU	FCH JU 278629	Adelan, EADS UK, Birmingham University	HyGear fuel cell systems	€4.2m	€2.1m	36 months from Dec 11	€1.4m
STAMPEM	Stable and low cost Manufactured bipolar plates for PEM Fuel Cells	FCH JU	FCH JU 303449	Teer Coatings Ltd, Miba Coatings Group	Stiftelsen SINTEF, Norway	€5.2m	€2.6m	36 months from July 12	€1.7m
PUMA MIND	Physical bottom Up Multiscale	FCH JU	FCH JU	Vodera Ltd	CEA. France	€4.1m	€2.3m	36	€1.4m

	Modelling for Automotive PEMFC Innovative performance and Durability optimization		303419					months from Dec 12	
IMPACT	Improved lifetime of automotive application fuel cells with ultra-low pt-loading	FCH JU	FCH JU 303452	ITM Power, Johnson Matthey Fuel Cells Limited	DLR, Germany	€8.8m	€3.9m	42 months from Nov 12	€2.5m
SWARM	Demonstration of Small 4-Wheel fuel cell passenger vehicle Applications in Regional and Municipal transport	FCH JU	FCH JU 303485	University of Birmingham, University of Coventry, Birmingham city council	PLANET, Germany	€17.6m	€7.0m	48 months from Oct 12	€4.4m
TriSOFC	Durable Solid Oxide Fuel Cell Tri-generation system for low carbon Buildings	FCH JU	FCH JU-2011-303454	University of Birmingham	University of Nottingham, UK	€2.7m	€1.48m	36 months from Aug 12	€0.9m
T-CELL	Innovative SOFC Architecture based on Triode Operation	FCH JU	FCH JU 298300	MANTIS Deposition LTD	Centre for Research & Technology Hellas, Greece	€3.4m	€1.8m	36 months from Sep 12	€1.1m
HyLIFT	Large scale demonstration of fuel cell powered material handling vehicles	FCH JU	FCH-JU 303451	Element Energy	Ludwig-Bölkow-Systemtechnik GmbH, Germany	€20.3m	€9.3m	48 months from Jan 13	€5.1m
HYPER	Integrated hydrogen power packs for portable and other autonomous applications	FCH JU	FCH JU 303447	University of Glasgow	Orion Innovations, UK	€3.9m	€2.2m	36 months from Sep 12	€1.3m
SAPIENS	SOFC Auxiliary Power In Emissions/Noise Solutions	FCH JU	FCH-JU 303415	Auto-Sleepers	Adelan Ltd, UK	€2.27m	€1.59m	36 months from Nov 12	€0.7m
Hyindoor	Pre Normative Research on the in-door use of fuel cells	FCH JU	FCH JU 278534	CCS Global Group Ltd,	L'Air Liquide S.A	€3.7m	€1.5m	36 months	€1.2m

	and hydrogen systems			Health and Safety Lab, University Ulster				from Jan 12	

9. International Initiative

Return to Top

Table 9.1: International Activities

Name	Type	Description	UK Contact Point
International Partnership for the Hydrogen Economy	Voluntary international framework driven by the US. Includes key developing countries	The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) was established in 2003 as an international institution to accelerate the transition to a hydrogen economy. Each of the following partner countries (18 including the UK) has committed to accelerate the development of hydrogen and fuel cell technologies to improve the security of their energy supply, environment, and economy	
IEA Implementing Agreement on Hydrogen Production and Utilisation	IEA Implementing Agreement	Allows interested Member and non-Member governments to pool resources and research the development and deployment of particular technologies.	Mr Ray Eaton ray.eaton@decc.gsi.gov.uk Dept. Energy & Climate Change
International Atomic Energy Agency	Research collaboration	Role of Nuclear Based Techniques in Development and Characterization of Materials for Hydrogen Storage and Fuel Cells	Dr S Skinner s.skinner@imperial.ac.uk Imperial College London
SECA (US DoE)	US Government funding (Department of Energy) to industry-led teams.	SECA – Solid State Conversion Alliance. LG Fuel Cell Systems Inc. (LGFCS), formerly known as Rolls-Royce Fuel Cell Systems (US) Inc leads a SECA consortium focussed on realising SOFC technology for distributed power generation with initial application to pulverised coal fuel. UK participants are Rolls-Royce Fuel Cell Systems Limited, Loughborough and Derby, UK (more information at page 35 of http://www.netl.doe.gov/technologies/coalpower/fuelcells/publications/Fuel-Cell-Annual-Report-2012.pdf)	